Projection of Chinese Motor Vehicle Growth, Oil Demand, and CO_2 Emissions Through 2050

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During this study a methodology was developed to project growth trends of the motor vehicle population and associated oil demand and carbon dioxide (CO_2) emissions in China through 2050. In particular, the numbers of highway vehicles, motorcycles, and rural vehicles were projected under three scenarios of vehicle growth by following different patterns of motor vehicle growth in Europe and Asia. Projections showed that by 2030 China could have more highway vehicles than the United States has today. Three scenarios of vehicle fuel economy were also developed on the basis of current and future policy efforts to reduce vehicle fuel consumption in China and in developed countries. With the vehicle population projections and potential vehicle fuel economy data, it was projected that in 2050 China's on-road vehicles could consume approximately 614 million to 1,016 million metric tons of oil (or 12.4 million to 20.6 million barrels per day) and emit 1.9 billion to 3.2 billion metric tons (or 2.1 billion to 3.5 billion tons) of CO_2 each year. Although these projections by no means imply what will happen in the Chinese transportation sector by 2050, they do demonstrate that an uncontained growth in motor vehicles and only incremental efforts to improve fuel economy will certainly result in severe consequences for oil use and CO_2 emissions in China.

During the past two and a half decades, China has experienced rapid growth in its on-road motor vehicle population, and this trend will certainly continue. The effects of this rapid growth on oil demand and carbon dioxide (CO_2) emissions have been a focus of study since the late 1990s. The Chinese government has undertaken efforts to improve vehicle fuel economy to help contain the significant increase in the nation's demand for transportation oil. For example, in 2004, China adopted the first fuel consumption standards for M1 vehicles [passenger cars, minivans with fewer than nine seats, and sport utility vehicles (SUVs)] to help reduce the fuel consumption rates of these vehicles by about 15% from those of Chinese M1 vehicles model year (MY) 2002 (*1*).

Several studies have been conducted to forecast the oil demand and CO_2 emissions of Chinese motor vehicles in the future (*2–4*). However, these studies omitted the impact of rural vehicles in their projections; these vehicles could account for 20% of the total oil consumption by motor vehicles in China. In addition, because of the rapid changes in Chinese vehicle fleets during the past 10 years, results of these studies—all of which were limited by the availability and reliability of data—need to be revised and updated.

During this study, a methodology was developed to simulate the growth of the Chinese vehicle population and resulting oil consumption and CO_2 emissions through 2050. Highway vehicles, motorcycles, and rural vehicles were included in this study. Vehicle population growth, vehicle use intensity, and vehicle fuel consumption rates were projected by considering (*a*) recent historical data available in China, (*b*) vehicle population growth patterns in developed countries that are applicable to China, and (*c*) scenarios that address important parameters for Chinese vehicle growth and fuel consumption rates. This study is an extension and enhancement of a study by two of the authors in 2000 (*4*). The intent is to provide a reasonable view of China's on-road vehicle population growth and the associated oil demand and CO_2 emissions so that effective policies can be formulated and implemented to address the adverse consequences of such growth.

METHODOLOGY AND DATA

Chinese vehicle classification is somewhat different than that in developed countries and has sometimes caused confusion outside China. Chinese civil vehicles are grouped into the following categories: highway vehicles (HWVs), motorcycles (MCs), and rural vehicles (RVs). According to Chinese statistical protocol, HWVs include passenger cars, trucks, and buses. On the basis of their gross vehicle weight (GVW), trucks are further classified into heavy-duty trucks (HDTs) [GVW ≥ 14 metric tons (MT)], medium-duty trucks (MDTs) (GVW = 6–14 MT), light-duty trucks (LDTs) (GVW = 1.8–6 MT), and minitrucks (MiniTs) (GVW < 1.8 MT). Total vehicle length (TVL) determines the classification of buses: heavy-duty buses (HDBs) (TVL ≥ 10 m), medium-duty buses (MDBs) (TVL = 7–10 m), light-duty buses (LDBs) (TVL = 3.5–7 m), and minibuses (MiniBs) (TVL = < 3.5 m). On the basis of engine displacement volume (DV), cars are classified into large cars (LCs) (DV ≥ 1.6 L) and small cars (SCs) (DV < 1.6 L). Motorcycles are classified as urban or rural, and RVs as three-wheeled (3-W RVs) or four-wheeled (4-W RVs). Car, truck, and bus types are further separated into gasoline and diesel vehicles; all MCs are fueled with gasoline and all RVs with diesel.

Projection of HWV Stock (by Model Year)

Vehicle stock is a key factor in determining oil use and CO_2 emissions in the transportation sector. Furthermore, vehicle technologies

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improve over time as a result of either government requirements or market competition. Because technology improvements could result in increased vehicle fuel economy over time, fuel economy usually varies by the vintage of on-road vehicle fleets. In China, where vehicle technologies are less advanced, the variation in vehicle fuel economy among different MYs could be significant. Therefore, an accurate projection of oil use and CO_2 emissions needs to take into account differences in the fuel economy of different MY vehicles on the road in a given calendar year. In other words, information on HWV stocks by vintage, as well as total HWV stocks, is needed. In this study the HWV ownership per 1,000 people was first projected by using the Gompertz function (as explained below) to obtain total HWV population with projected human population in China. Then, annual sales of vehicles were backcalculated to match the projected total HWV stocks in a given year by considering vehicle survival rates and market shares by vehicle type. Note that in this step, the total HWV stock was also decomposed into different vehicle types by using their market shares. Finally, HWV stock was established by vintage and by type on the basis of HWV sales, survival rates, and market shares.

Total HWV Stock: Gompertz Function

The Gompertz function, which is used to simulate the growth of the HWV fleet in this study, can be expressed as

$$V_i = V^* \times e^{\alpha a^{\beta \mathrm{EF}_i}} \quad (1)$$

where

V_i = HWV ownership in year i (vehicles per 1,000 people),
V^* = ultimate saturation level of HWV ownership (vehicles per 1,000 people),
EF_i = economic indicator [gross domestic product (GDP)/capita was used], and
α and β = two parameters that determine the shape of the S-shape curve of HWV ownership growth over economic growth.

The Gompertz function relates HWV ownership to per capita GDP by following an S-shape growth curve against per capita GDP growth with three phases: an initial slow growth period, a boom period, and a saturated growth period. In Figure 1, the HWV ownership per 1,000 people is plotted over per capita GDP in 18 countries using data from various references (*5–10*). Growth patterns in HWVs were grouped into three categories. The first category is the North American pattern, represented by that in the United States, in which the HWV fleet grows most rapidly as per capita GDP increases. For this pattern, a saturation level as high as 800 vehicles per 1,000 people is reached as per capita GDP reaches $20,000 (1985 dollars). The second pattern is the European pattern, in which the growth rate of HWV ownership versus per capita GDP is slower than that of the North American pattern. This is reflected in both the slope of the growth curve and the saturation level and could be partially attributable to the denser population and compact urban development in European countries. The saturation level for the European growth pattern is about 600 vehicles per 1,000 people. The third pattern is the Asian pattern, represented by Japan. The saturation level of HWV ownership in Japan is relatively lower—about 550 vehicles per 1,000 people. This low saturation level is caused partly by the high population density and the extensive public transportation system in Japan. Some countries, such as South Korea, Denmark, and Ireland, show an even smaller rate of HWV ownership.

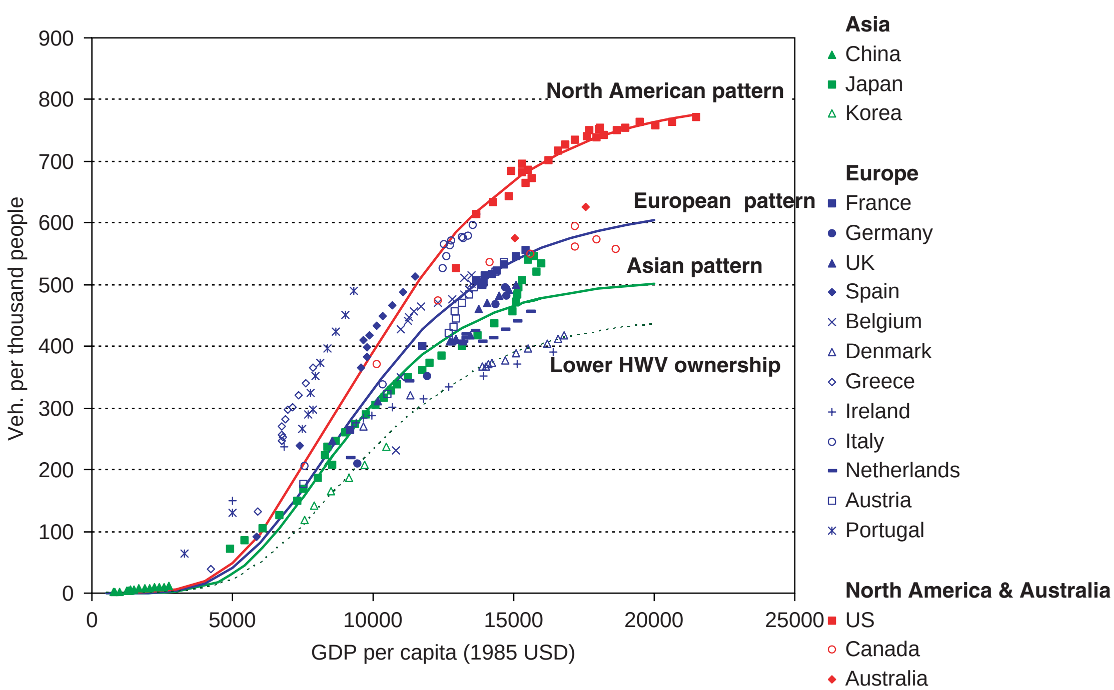

FIGURE 1 Growth trends of vehicle ownership in selected countries [vehicle stock data for European countries are from the European Commission (*6*), for South Korea from the Korean Automobile Manufacturers Association (*7*), for China from the State Statistical Bureau of China (*8*), and for other countries from Davis and Diegel (*5*); GDP per capita data are from Easterly (*9*); population data are from the U.S. Census Bureau (*10*)].

The saturation level of HWV ownership per 1,000 people is a key factor in estimating total HWV population. Dargay and Gately assumed a saturation level of 850 (all vehicles) per 1,000 people and 620 cars per 1,000 people for the 26 countries (including China) that they studied (*11*). However, Kobos et al. believe that it was impossible for China—a highly populated country—to reach such a high saturation level (*3*). Instead, Kobos and his colleagues used a saturation level of 292 passenger vehicles per 1,000 people. Button et al. (*12*) set a range of 300 to 450 cars per 1,000 people for developing countries such as China. On the basis of the historical information about HWV growth in developed countries, three scenarios were established for growth in the stock of Chinese HWVs: a high-growth scenario (following the European growth pattern), a midgrowth scenario (following the Japanese growth pattern), and a low-growth scenario. Saturation levels for HWVs of 600, 500, and 400 per 1,000 people were selected for the high-, mid-, and low-growth scenarios, respectively. These saturation levels are for all HWVs, including passenger cars.

On the basis of the current Chinese government's economic projection (according to the Report of the 16th National Congress of the Communist Party of China, the government's plan is to increase its GDP four times between 2000 and 2020 and to reach a per capita GDP of $10,000 by 2050) and other available references (*13–16*), a Chinese annual GDP growth rate of 8.0% between 2006 and 2010 and of 6.0%, 4.7%, 4.0%, and 3.0% during each 10-year period from 2011 to 2050 was assumed.

Thus, with projected total human population, total HWV stock in China can be predicted from the projected vehicles per 1,000 people. The Chinese population is projected to increase from the current 1.30 billion to 1.45 billion by 2050 (*13, 17, 18*).

HWV Sales by Type: A Backcalculation Method

Assuming that vehicle stock in a given year consists of the portion of the vehicles sold in all previous MYs that are still on the road, the total vehicle population can be expressed as Equation 2. Given vehicle survival rates and market shares by type, this equation was used to backcalculate annual vehicle sales to match the already projected total HWV.

$$\mathrm{VP}_i = \sum_j \sum_{k=0}^{\sigma} \left(\mathrm{sales}_{i-k} \times \mathrm{market}_{i-k,j} \times \mathrm{SR}_{k,j}\right) \qquad (2)$$

where

σ = possible longest service period of the vehicles (years),
k = age in k years for vehicles,
VP_i = vehicle population in year i (million units),
sales_{i-k} = sales of all vehicle types in model year $i–k$ (million units),
$\mathrm{market}_{i-k,j}$ = market share of vehicle type j in model year $i–k$ (%), and
$\mathrm{SR}_{k,j}$ = survival rate of vehicle type j at age k (%), the proportion of still-operating vehicles (in sales) in certain years.

Vehicle survival rates (SRs) and market shares need to be determined for Equation 2. So far, relatively little is known about the survival rates of HWVs in China. However, the SRs of China's vehicle fleets are certainly affected by Chinese national scrappage standards, which require that vehicles be scrapped when they reach a defined age or mileage; for example, passenger vehicles with nine or fewer seats are required to be scrapped after 15 years and trucks at 400,000 km of travel distance or 10 years of service. In this study, SRs are determined on the basis of vehicle scrappage requirements in China and the trends in variation of SRs in developed countries. In particular, the SRs of various vehicle types in China are assumed to closely follow those in Beijing, as presented in a study by Yang et al. (*19*), but with a different median lifetime (defined as the vehicle age at which the SR equals 50%; in this study the median lifetime is determined for each vehicle type on the basis of its required scrappage period). For future years, an increase of 2 to 3 years in the median lifetime was assumed for cars, MiniBs, and LDBs for MYs after 2020. The SRs of other vehicle types were assumed to remain unchanged.

Trends in vehicle composition were projected according to government policies, the development plan of the Chinese auto industry (*20*), and the historical trends in some developed countries. The following factors were taken into account to determine the composition of vehicle types. First, sales of passenger cars will continue to increase, and the share of truck sales will gradually decrease. Second, the proportion of small cars in the car population could begin to increase in the near future because of recent government policies to encourage the purchase of small cars and because of budget car purchases by middle-income families (On April 1, 2006, the Chinese central government set the national vehicle sales excise tax rates for passenger cars to encourage sales of small cars). Third, shares of diesel vehicles in the Chinese vehicle fleet could increase in the future.

Projection of Motorcycle Stock

The MC population has been increasing at an annual rate of 17% in China during the past 15 years. In 2004 the MC stock in China was about 67 million (*8*). Unlike the pattern for HWVs, the ownership growth pattern for MCs varies greatly in different countries. The growth of MCs could be influenced by three sets of factors: (*a*) economic factors, (*b*) geographical factors, and (*c*) other factors.

Economic Factors

According to surveys that address urban families with different income levels in China who own MCs and HWVs in different years (*8*), MC ownership in families with per capita income below 20,000 yuan (8.3 yuan = $1.00; 2003) rises as per capita income increases. However, when per capita income reaches 20,000 to 30,000 yuan (2003 price), the MC growth rate appears to slow, reaching a saturation level. Also at this income level, car purchases begin to increase rapidly, suggesting that a switch from MCs to passenger cars occurs in urban families as income rises. Although it is still unclear how HWV and MC ownership in China will change when per capita income increases to more than 30,000 yuan, MC ownership could start to decline as income continues to increase. As people move up from one income level to the next, average MC ownership per 1,000 people can vary greatly. In this study it was assumed that within a given income level, MC ownership per 1,000 people will remain the same. Total MC population is projected by the distribution of income levels.

Geographical Factors

Geographical features are important factors influencing MC stock. Nagai et al. (*21*) summarized the trend associated with MC ownership in Asian countries and found that MC ownership tends to increase as per capita GDP grows, except in several geographically unique countries and areas, such as the Philippines, which is archipelagic, and Singapore, which is a city state. In China, because geographical features vary dramatically throughout the country, MC ownership is different from region to region. For example, the level of MC ownership in Hainan Province is 64 per 1,000 people and is still growing at an annual rate of 17%, whereas in Sichuan, the level of MC ownership has stabilized at only 9.2 per 1,000 people. Note that per capita income in the two provinces is similar. MC ownership by rural families is generally higher than that by urban families in China. This difference is also attributable partly to policies in major Chinese cities to limit, and even ban, the registration and use of MCs in urban areas. An implication is that rural MCs have greater potential for growth than urban MCs in the foreseeable future. Also, generally MC ownership in southern regions is higher than in the northern regions because the warmer southern climate makes riding MCs more comfortable. MC ownership in the western provinces is much lower than in the eastern provinces because of lower income and mountainous geography in the west. Therefore the 31 provinces in China were divided into three regions: the northern, southern, and western regions. In addition, urban and rural MC stocks were projected separately.

Other Factors

Other factors include MC restriction policies and policies that influence the use of MCs or cars. The fluctuation in MC ownership in the United Kingdom is a typical example. Duffy and Robinson (*22*) stated that the second growth period for MCs during the two oil crises in the 1970s in the United Kingdom was probably related, to some extent, to the lower fuel consumption by MCs. They also considered that the upswing in MC ownership in the United Kingdom since the mid-1990s might be the result of the recent government efforts to inhibit car use in major cities to relieve congestion. Also, a surge in MC sales has been observed in the United States in 2006 because of high gasoline prices. These factors are difficult to specify when projecting MC stock—some are even unpredictable. In this study, only the quantifiable factors are taken into account, such as the restrictions mentioned above on MC registration and use in urban areas in China.

The following equation was used to simulate the MC stock in China:

$$\mathrm{MC}_i = \sum_j \left[\mathrm{inc\_dis}_j \times M_j^* \times \left(1 - \mathrm{res}_i\right) \right] \tag{3}$$

where

MC_i = MC ownership per 1,000 people in year i,
j = income level j (per capita income classified into 11 income levels, with more levels at lower incomes because MC ownership is more sensitive to income at lower income levels),
$\mathrm{inc\_dis}_j$ = income distribution, that is, the share of the total population (%) in income level j (lognormal distribution used to simulate the income distribution),
M_j^* = MC ownership per 1,000 people for the population in income level j [on the basis of statistics, historical trends of MC stock, and other survey studies (*8, 23*), M^* set for the first to the ninth income level for the six regions—northern urban, northern rural, southern urban, southern rural, western urban, and western rural], and
res_i = restriction factors in year i, which reflect the effect of possible policies to restrict the use of MCs. However, this factor is difficult to quantify. In this study, it was assumed that M^* will be reduced by 20% of total MC population in urban areas after 2020, another 5% after 2030, and another 5% in 2040 as a result of potential policy intervention.

Projection of Rural Vehicle Stock

With a rural population of 925 million, China has a large population of RVs—about 22 million in 2001 (*24*). Because the registration requirements for RVs in China are weak, the statistical data for RVs from different official statistical sources are inconsistent and may not provide accurate information about Chinese RVs. Main reliance was on information released by the Chinese RV industry and related organizations.

The production of RVs in China increased at a rapid annual rate of 38% between 1985 and 2000—a higher rate than that for HWVs. This rapid growth was caused partly by the much more lenient requirements and weaker regulations for RVs compared with HWVs. The production growth of RVs in China has slowed down in recent years, probably as a result of slower growth in the income of rural families and stringent new regulatory conditions for using RVs (*25*).

Problems related to safety and the pollution generated by RVs have already raised government concerns. Efforts are under way to develop and enforce RV regulations from RV production through registration and to improve RV technologies to increase the safety of RVs and reduce emissions. Nevertheless, the Chinese RV stock still shows a huge potential for growth because of the low rate of ownership: 9.3 RVs per 100 rural households in 2001 (*25*). The increase in per-rural-family income and improvements in the condition of rural roads could result in growth of RV stock. According to a survey conducted by authorities in more than 20 provinces that addressed the willingness of families to purchase an RV, 5% of rural families were willing to purchase an RV in the next 3 years (*26*).

Somewhat similar to MCs, RVs could be a transitional transportation means because of their much lower price. When their per capita income increases, rural families could turn to more comfortable modes such as LDTs. Therefore, the RV stock was projected by using the same method as that used for projecting the MC stock. The RV ownership per 1,000 rural people was estimated from available data for 11 income levels (*27*). A switching factor was established to reflect a potential switch from RVs to LDTs or MDTs as income moves up from Level 5 to Level 11. A restriction factor that reflects the influence of policies was also established for RV ownership. The split between ownership of 3-W RVs and 4-W RVs was about 80% and 20% in 2000 (*28*).

Vehicle Miles Traveled

Vehicle miles traveled (VMT) data in China are not readily available or published. The limited VMT data that were obtained from the available literature provide some helpful information about the characteristics of VMT by the Chinese vehicle fleet. Table 1 shows the annual VMT of the vehicle types examined in this study for China and for several other countries.

TABLE 1 Comparison of Annual VMT Projections in Study with VMT in Selected Countries

Country	China[a]			Japan[b]	United States[c]	United Kingdom[e]	France[e]	Germany[e]
Year	2000	2030	2050	1999	2002	1999	1999	1998
Cars	24	13	12	8	19	17	15	12
Trucks								
HDTs	40	50	55	78	71	25	20	13
MDTs	25	24	24	50	21			
LDTs	21	20	20	30–40	20			
MiniT	20	15	14		19			
Buses								
HDBs	40	35	35	13	20[d]	60	29	44
LDBs	35	20	20					
MCs	9	5	4		3.1[d]	6.7	1.7	3.4
RVs								
3-W	15	15	15					
4-W	28	28	28					

VMT = km thousands.
[a]The weights of MiniTs, LDTs, MDTs, and HDTs in China are <1.8 MT, 1.8–6 MT, 6–14 MT, and ≥14 MT, respectively.
[b]From Minato and Hirota (*29*). Trucks here are commercial trucks, and the weights of LDTs, MDTs, and HDTs in Japan are 4–6 MT, 7–8 MT, and >10 MT, respectively.
[c]From Davis and Diegel (*5*), pp. 5–6. The weights of MiniTs, LDTs, MDTs, and HDTs in the United States are ≤2.7 MT (≤6,000 lb), 2.7–4.5 MT (6,001–10,000 lb), 4.5–11.8 MT (10,001–26,000 lb), and >11.8 MT (>26,000 lb), respectively.
[d]From FHWA (*30*), 2001 data.
[e]From FHWA (*30*).

Cars

According to the available survey results in China, the annual VMT of cars in cities has been about 24,000–27,000 km in the past few years (*31, 32*). Compared with the VMT of other developed countries, the current Chinese car fleet VMT is much higher, which is caused by the high percentage of taxis in the Chinese car fleet (16.4% in 2002 and 10.1% in 2004) and their high annual mileage (90,000–115,000 km). As the number of private cars grows rapidly, the annual mileage of cars will decrease. It was therefore assumed that the annual VMT by cars will decrease and eventually reach 12,000 km per year in 2050, which is about the current level in Western Europe, as shown in Table 1.

Trucks and Buses

According to He et al. (*2*), HDTs in China travel about 50,000 km annually, and MDTs and LDTs travel 20,000–25,000 km each year (*2*). Other researchers reported 20,000 km per year for HDTs (*4, 31*). As Table 1 shows, HDTs in the United States and Japan tend to have higher VMT than LDTs because HDTs are mainly business owned and most of them are used for long-distance transport. In this study, an increasing trend for HDT annual VMT and a stable trend for LDT and MDT annual VMT were projected. The annual VMT for buses are somewhat similar to those for trucks. Larger buses tend to travel farther than smaller ones.

MCs

Previous research has found that the current Chinese MC annual VMT ranges from 4,000 to 10,000 km (*29, 33, 34*). Worldwide, the annual VMT of MCs varied from 1,700 to 6,700 km during the 1990s (Table 1) (*30*). It was assumed that annual VMT for Chinese MCs will decrease from 9,000 km in 2000 to 4,000 km in 2050.

RVs

The annual VMT of current RVs was estimated by using their scrappage mileage (*35*) and their average scrappage age. It was further assumed that the annual VMT of RVs will remain constant in the future.

Fuel Economy of Vehicles by Model Year

The data in He et al. (*2*), Sperling et al. (*35*), and the Development Research Center (*36*) were used to estimate the fuel economy of vehicles by MY before 2005. Three scenarios were developed to estimate the fuel economy of future new motor vehicles in China: a conservative scenario, a moderate scenario, and an aggressive scenario. The scenarios were established on the basis of the U.S. National Academy of Sciences (NAS's) Paths (*37*) (NAS defined three fuel economy improvement paths based on market potentials of fuel economy improvement technologies and economic/regulatory conditions. Path One assumes likely market-responsive advances in fuel economy using production-intent technologies that could be introduced in the next 10 years. Path Two assumes more aggressive advances in fuel economy that employ more costly production-intent technologies but that are technically feasible for introduction in the next 10 years if economic and regulatory conditions justify their use. Path Three assumes even greater fuel economy gains, which would necessitate the introduction of emerging technologies that have the potential for substantial market penetration in 10 to 15 years.) and Japanese fuel consumption requirements for heavy-duty vehicles (*38*), as shown in Table 2. Under the conservative scenario, the fuel economy

TABLE 2 Fuel Economy Scenarios for Chinese Highway Vehicles

	Conservative Scenario	Moderate Scenario	Aggressive Scenario
LDBs, MiniBs, cars	NAS's Path One technologies began in 2005 in China	NAS's Path One technologies began in 2005 in China; NAS's Path Two technologies will begin in 2012 in China	NAS's Path One technologies began in 2005 in China; NAS's Path Three technologies will begin in 2012 in China
LDTs, MiniTs	NAS's Path One technologies will begin in 2008 in China	NAS's Path One technologies will begin in 2008 in China; NAS's Path Two technologies will begin in 2016 in China	NAS's Path One technologies will begin in 2008 in China; NAS's Path Three technologies will begin in 2016 in China
HDBs, MDBs, HDTs, MDTs	Japanese HDT fuel consumption requirements will begin in 2020 in China	Japanese HDT fuel consumption requirements will begin in 2016 in China	Requirements 20% more stringent than Japanese HDT fuel consumption; requirements will begin in 2016

of new cars in China will be equivalent to that in the United States by 2030.

Calculation of Oil Use and CO_2 Emissions

Oil use was calculated by using vehicle stock by vintage, VMT, and fuel economy of vehicles (by MY). Carbon dioxide emissions were calculated based on the assumption that all the carbon in fuels will be converted to CO_2 eventually, so CO_2 results in this study are the so-called pump-to-wheels (PTW) results. To take into account CO_2 emissions generated during the production and delivery of gasoline and diesel, researchers could use well-to-wheels (WTW) CO_2 emission factors per unit of fuel used. Usually, WTW CO_2 emissions are 20% higher than PTW CO_2 emissions.

RESULTS AND ANALYSIS

Projected Total Chinese Vehicle Stock

By 2050 the HWV stock in China is projected to reach 486 million to 662 million (see Figure 2) and will match the current U.S. vehicle stock level between 2027 and 2028. By 2035 the Chinese HWV stock will reach 321 million to 391 million, which will be similar to the projected U.S. vehicle stock of 330 million by 2030 (*39*). After 2035 China will potentially have the largest HWV fleet in the world, even under the low-growth scenario. Moreover, even by 2050, the number of HWVs per 1,000 people in China will not reach the saturation point, so the Chinese HWV stock will still have the potential to grow after 2050.

Table 3 shows the projected vehicle stock by type. The number of passenger cars is expected to dramatically increase in the future. Under the low-growth scenario, the total number of cars in China will reach the current U.S. car population by about 2020. Even under the low-growth scenario, the increase in the absolute number of cars in China will be extraordinarily high as a result of significant growth in GDP and China's high population. Note that Ng and Schipper projected a Chinese car population of 145.7 million by 2020 under the business-as-usual scenario and 72 million to 131 million under alternative vehicle-constraining scenarios (*40*). Their projected car population is much larger than the projected population of this study—87 million to 93 million in 2020.

The number of trucks will also increase at an annual rate of 5.0% to 5.7% through 2050, reaching 86 million to 118 million by 2050. The number of MCs (the largest vehicle fleet in China at present) will continue to grow during the next 20 to 25 years to reach 92 million by approximately 2030. Then, the number will gradually decline as a result of an increase in family income in China and the consequent switch from MCs to cars. This trend was driven by the assumption that MC ownership will decline at higher income levels. By 2050

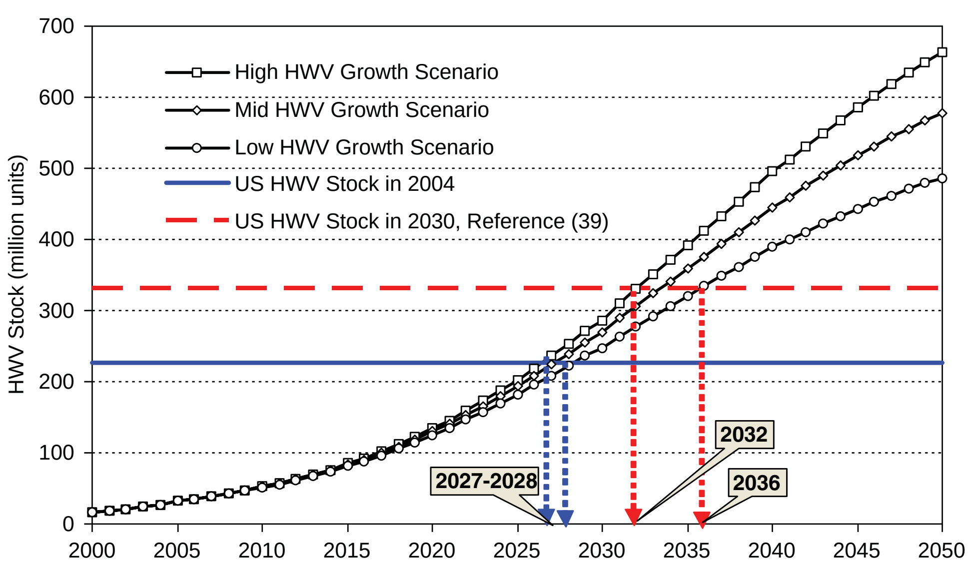

FIGURE 2 Projected Chinese HWV stock between 2000 and 2050.

TABLE 3 Projected Chinese Vehicle Stock

	2000	2010	2020	2030	2040	2050
Low-growth scenario						
Total highway vehicles	16	52	125	247	389	486
Cars	4	26	87	186	306	391
Trucks	7	15	27	47	70	86
Buses	4	11	11	13	13	10
HWVs/1,000 people	13	39	90	174	270	335
High-growth scenario						
Total highway vehicles	16	53	134	287	495	662
Cars	4	27	93	217	389	532
Trucks	7	15	29	55	89	118
Buses	4	11	12	15	17	13
HWVs/1,000 people	13	39	97	202	344	456
Total MCs	44	77	95	92	61	44
MCs/1,000 people	35	58	69	65	42	30
Total RVs	21	40	45	41	32	28
RVs/1,000 rural people	23	53	76	90	81	83

NOTE: Vehicle stock in millions.

China will have 44 million MCs. The population of RVs will steadily increase to 45 million by 2020; then RV population will gradually decrease to 28 million by 2050.

Projected Annual Highway Vehicle Sales

By 2050, annual sales of HWVs could reach 42 million to 59 million, which is about 10 times today's annual sales level. By 2022–2023, annual HWV sales will reach 20 million, and then in less than 10 years, annual sales will reach at least 30 million. In comparison, total annual vehicle sales in the United States is 17 million, of which 7.5 million are passenger cars and 9.5 million are trucks (*41*). The projection shows that starting in 2007, passenger car sales will exceed sales of trucks and buses combined. Annual passenger car sales could reach 10 million by 2017, 20 million by 2027, 30 million by 2036, and 40 million by 2050.

Projected Annual Oil Consumption and CO_2 Emissions

Figure 3 shows the projected oil demand by Chinese motor vehicles (including HWVs, RVs, and MCs) under nine combinations of the three vehicle growth scenarios and the three fuel economy improvement scenarios. In 2005, on-road Chinese vehicles consumed a total of 108.6 million MT of oil (2.2 million barrels per day), which was about one-third of the total national oil consumption. The oil demand by the Chinese road transportation sector will rise rapidly, reaching 614 million–1,016 million MT per year (or 12.4 million to 20.6 million barrels per day) by 2050.

According to Figure 3, the oil demand by the road transportation sector in China will match that in the United States by 2030–2041. Relative to the growth pattern of the vehicle population (see Figure 2), it will take some additional years for China to match the oil demand of road transportation in the United States because Chinese vehicles will be smaller than U.S. vehicles and will most likely have lower energy intensity.

The combination of the high-growth scenario and the conservative fuel economy improvement scenario results in the highest oil demand in 2050—65% higher than that under the combination of the low-growth scenario and the aggressive fuel economy scenario. In a way, the difference between these two combinations shows the potential for energy conservation that can result from containing Chinese vehicle population growth and improving vehicle fuel economy. Furthermore, under any given vehicle growth scenario, oil demand under the aggressive fuel economy improvement scenario in 2050 is 23% lower than that under the conservative scenarios, which results in a savings of 141 million–192 million metric tons (2.9 million to 3.9 million barrels per day) of oil by 2050.

The demand for diesel by motor vehicles increases much more rapidly than does the demand for gasoline. In 2050 the demand

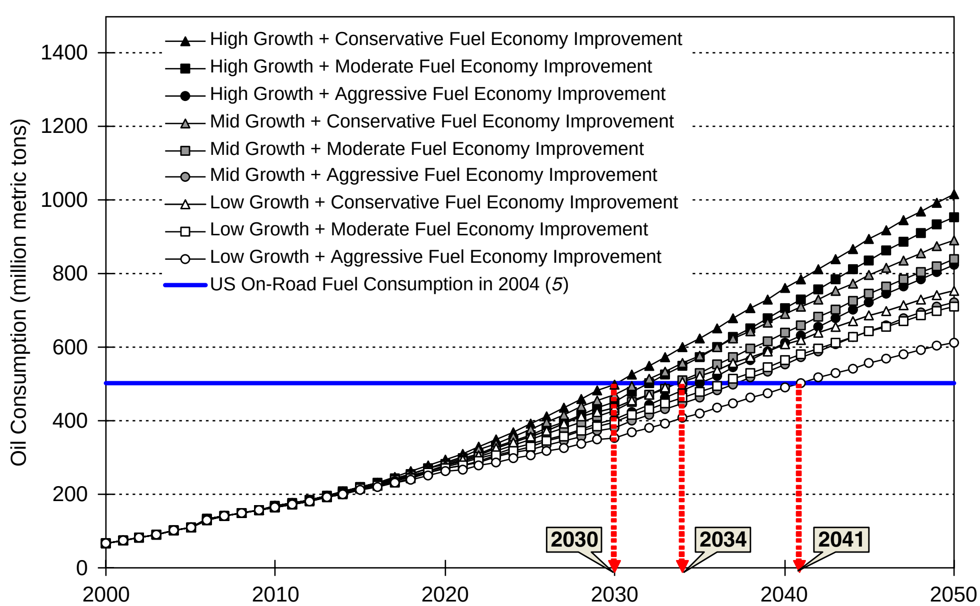

FIGURE 3 Projected annual oil demand by Chinese motor vehicles under nine combinations of scenarios.

for gasoline and diesel will be 179 million to 317 million metric tons and 435 million to 699 million metric tons, respectively. The demand for diesel to fuel Chinese on-road vehicles will be about two-thirds of total transport oil demand by 2050.

In 2005, oil consumption levels for cars, buses, trucks, MCs, and RVs were 13.4%, 15.9%, 35.7%, 10.0%, and 25.0%, respectively. This study's projection shows that cars and trucks will be the largest consumers of oil in Chinese road transportation in the next half century. Cars have already been targeted for oil savings worldwide. The oil consumption share by cars in China will account for 30%–31% of the total oil demand by HWVs in 2050. However, although the share of trucks in the HWV category will be decreasing to below 25% by about 2015, all trucks together will still consume the largest share of oil through 2050—suggesting that China needs to implement some effective measures to control oil consumption by trucks.

With a declining share of MC stock, the percentage of oil demand by MCs will decline from 10% in 2005 to below 0.3%–0.6% in 2050. RVs have been largely ignored in addressing energy use and emissions from motor vehicles in China. In fact, because of their large population, RVs consume a significant amount of oil. RVs consumed 18 million and 27 million metric tons of diesel in 2000 and 2005, respectively—accounting for more than 40% of the total diesel used in road transportation. In 2050 RVs will consume 24 million MT of diesel, accounting for 3.4%–5.6% of total diesel demand for road transportation in China. Some other studies reported that RVs consumed about 14 million to 19 million metric tons of diesel in 2000 (*34, 42, 43*); these estimates are quite close to the results of the present study.

By 2050 Chinese motor vehicles could emit 1.9 billion to 3.2 billion metric tons (or 2.1 billion to 3.5 billion tons) of CO_2 under the nine combinations of scenarios—six to 10 times today's CO_2 emissions from Chinese motor vehicles. By 2028–2037, the CO_2 emissions of Chinese motor vehicles will match those of current U.S. motor vehicles (*44*).

CONCLUSIONS AND DISCUSSION

In this study, a model was developed to project total HWV, MC, and RV populations in China by 2050. To address the uncertainties associated with the growth in the number of Chinese vehicles and the potential to improve vehicle fuel economy, two sets of scenarios were developed: one covering the range of vehicle growth rates and the other the range of potential improvements in vehicle fuel economy.

By 2030 China could have more HWVs than the United States has today, and by 2035, it will probably have the most HWVs of any country in the world. By 2050 China could have 560 million to 730 million motor vehicles on the road. On the basis of scenarios projecting the growth of vehicle stock and improvements in fuel economy, on-road vehicles in China could consume 614 million to 1,016 million metric tons of oil a year (or 12.4 million to 20.6 million barrels of oil a day) and emit 1.9 billion to 3.2 billion metric tons (or 2.1 billion to 3.5 billion tons) of CO_2 a year in 2050, which would put tremendous pressure on the balance of Chinese (and, indeed, international) oil supply and demand. Another result will be serious concerns about the potential effects of Chinese motor vehicles on global climate change.

The findings of this study show that, although the population of Chinese HWVs could match that of HWVs in the United States before 2030, oil consumption by Chinese vehicles will match that of the current U.S. vehicle population between 2030 and 2041 (depending on vehicle growth and fuel economy improvement scenarios). The apparent lag of growth in oil consumption versus growth in vehicle population in China, in comparison with the growth in the United States, is largely the result of differences in vehicle fleet composition between the two countries. In China, the vehicle fleet consists of vehicles that are smaller than those in the United States, so the Chinese vehicle fleet could use less oil than the U.S. vehicle fleet. This difference in oil consumption demonstrates the importance of introducing small, efficient vehicles—which is indeed encouraged by recently adopted Chinese policies that introduce vehicle sales excise taxes.

Furthermore, although improvements in vehicle fuel economy are crucial in reducing transport energy use, simulations show that with the given assumptions, containing the growth of the vehicle population could have a profound effect by reducing oil use and CO_2 emissions.

Although the population of passenger cars will far exceed that of all truck types in China in the future, oil use and CO_2 emissions from the Chinese truck fleet will be far larger than those related to Chinese passenger cars. The reason is that trucks are very use intensive (higher VMT per year) and energy intensive (lower fuel economy). Unfortunately, fuel economy regulations for trucks are weak worldwide. Only very recently did Japan adopt fuel economy standards for HDTs. Chinese organizations recently began to evaluate potential fuel economy standards for heavy-duty vehicles. Such standards, with a timely implementation schedule, are urgently needed to control energy use by the Chinese truck fleet in the future.

The Chinese government is making a major effort to develop alternative transportation fuels to control China's oil imports. The potential use of alternative fuels in China has not been considered in this study. Although they may reduce oil use, alternative fuels that are produced from fossil energy sources may not reduce CO_2 emissions. Only if alternative fuels are produced from renewable sources (such as biomass) will their use help reduce both CO_2 emissions and oil use.

This study's projection of the oil demand by the Chinese road transportation sector is enormous. Researchers may question how such demand will be met, especially given that world conventional oil production may reach its peak before 2050. One way of interpreting these results is that, if China makes no effort to address oil use by and CO_2 emissions from its on-road vehicles, the Chinese transportation sector will have detrimental effects on global oil use and CO_2 emissions. However, by realizing the tremendous potential detrimental effects of unchecked oil use and CO_2 emissions, China could make efforts to address these issues by improving per-vehicle energy efficiency, promoting the use of alternative transportation fuels, and encouraging the use of more efficient transport modes (such as public transportation systems). Nevertheless, with the rapid economic growth, a huge population, and its citizens' desire for increased mobility, the Chinese transportation sector faces significant challenges in regard to sustainable resource supply and environmental protection. Meeting such challenges will require coordinated efforts both within China and between China and the international community.

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